transport on a wavy wall and the propagation of internal waves in the upper ocean thermocline. Finally, two new research topics were introduced to the CTR Summer Program, nanofluidics and biology. The biology work on the life cycle of phytoplankton where turbulence plays a key role is a natural extension of CTR's expertise. The work on nanofluidics, which is based on molecular dynamics, is an outgrowth of CTR's expertise in using advanced algorithms and large-scale simulations. Carbon nanotubes in water (fig. 2), and flow in a nanometer-scale channel were simulated during the Summer Program.

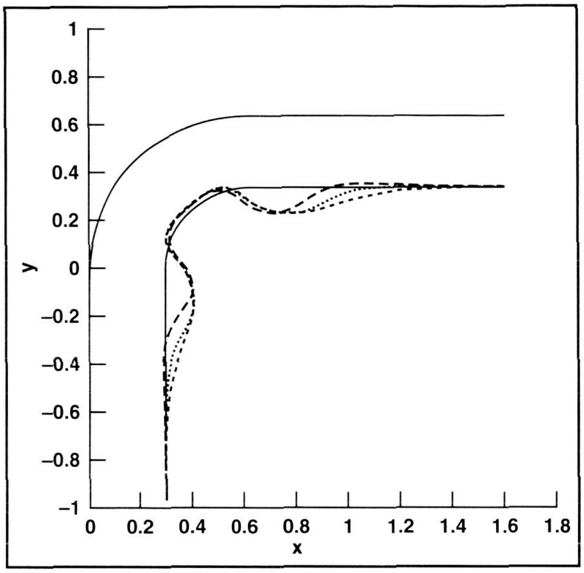

Fig. 1. Design of fluidic channels using a novel shape-optimization algorithm. The various lines show shapes obtained under the same optimization conditions for three admissible spaces with minimum required regularity for the shape. (See http://ctr.stanford.edu/summer00/mohamadi.pdf for a detailed report.)

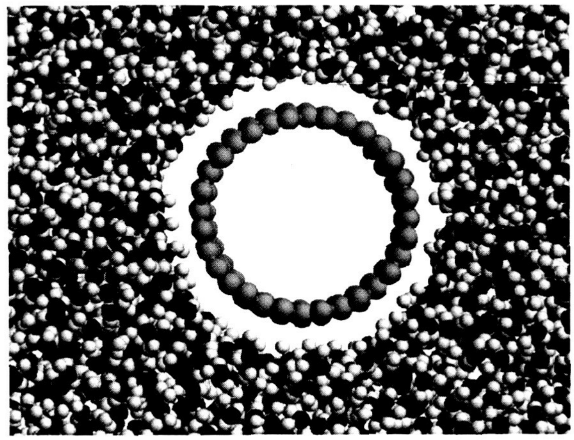

Fig. 2. Snapshot of the atoms from the simulation of a single carbon nanotube in water. (See http://ctr.stanford.edu/summer00/walther.pdf for a detailed report.)

There are 29 papers in the proceedings, grouped in six areas. Each group is preceded by an overview provided by its coordinator. The entire proceedings of the 2000 Summer Program are available on the World Wide Web (http://ctr.stanford.edu).

Point of Contact: Parviz Moin
(650) 604-5127
moin@rft33.nas.nasa.gov

The Effects of Turbulence on Phytoplankton

S. Ghosal, M. Rogers, A. Wray

Phytoplankton are photosynthesizing microscopic organisms that inhabit the upper sunlit layer (euphotic zone) of almost all oceans and bodies of fresh water. They are agents for "primary production," the incorporation of carbon from the environment into living organisms, a process that sustains the aquatic food web. Phytoplankton thus control the biogeochemical cycles in aquatic environments and thereby exert a dominant influence on life on Earth. This work is directed at understanding the effects of turbulence on the distribution of phytoplankton and extends earlier modeling efforts through a combination of analysis and computer simulation. The purpose is to better understand the principal qualitative aspects of the physical/biological coupling of this natural system.

Turbulence influences this process in three important ways. First, essential mineral nutrients are transported from the deeper layers to the euphotic zone by turbulence. Second, turbulence helps to suspend phytoplankton in the euphotic zone, since in still water the phytoplankton, especially the larger species, tend to settle out of the sunlit layers. Third, turbulence also transports phytoplankton from the surface to dark sterile waters, an important mechanism of loss. Thus, stable phytoplankton populations are maintained through a delicate dynamic balance between the processes of turbulence, reproduction, and sinking.

A simplified model of a phytoplankton population in isotropic turbulence was considered. The phytoplankton population growth is assumed to be limited by the available light intensity and not by the nutrient supply. The phytoplankton density is controlled by (1) turbulent advection, (2) the reproduction rate associated with the light intensity at a given depth, (3) the sinking speed of the particular phytoplankton being considered, and (4) the loss rate resulting from natural deaths and "grazing" by higher animals. For this simplified model, analysis indicates the possibility of a stable phytoplankton population for certain regions of a two-dimensional parameter space, these parameters being the dimensionless reproduction rate and the dimensionless height of the sunlit "euphotic" zone for clear water (these quantities being normalized by the turbulent phytoplankton diffusivity and the sinking speed in still water).

Several direct numerical simulations of this simplified model problem have been generated using a pseudospectral numerical method. The various simulations correspond to different conditions in the above-described dimensionless parameter space. Parameters below the critical curve result in decaying nonsustainable phytoplankton distributions, and those above the curve yield sustained populations. The simulation results for the horizontally averaged phytoplankton concentration as a function of water depth increase toward the theoretically predicted profile as time evolves, indicating good agreement with the theoretical analysis (fig. 1).

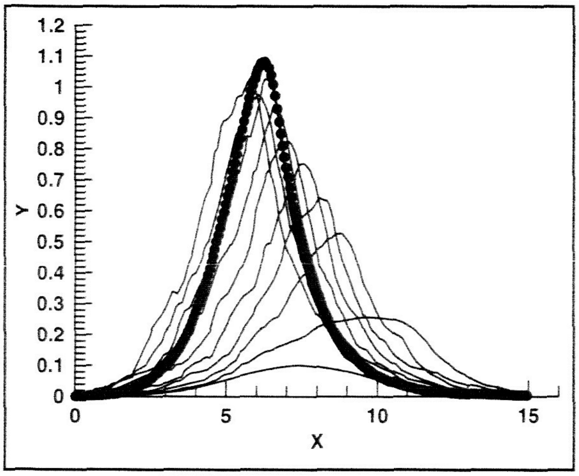

Fig. 1. The time evolution of the horizontally averaged plankton concentration as a function of water depth. The symbols represent the theoretically predicted profile.

Comparing the numerical simulations and the theory suggests that an eddy-diffusivity model for turbulent transport is adequate for the purpose of predicting the mean phytoplankton concentration. The simulations also confirm that the analytical mean phytoplankton profile is globally stable in the appropriate region of the parameter space.

The current model assumes that the plankton distribution is statistically homogeneous in the horizontal direction. This neglects the rich and varied horizontal structure seen in satellite images of plankton. The horizontal structure of phytoplankton concentrations and the manner in which the steady-state distribution in the above model gets established are subjects for future investigations.

Point of Contact: Mike Rogers
(650) 604-4732
mrogers@nas.nasa.gov